Conventional Tunneling in Urban Area
– Case History and Future Prospect in Japan

TRAINING MATERIAL PREPARED BY

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Introduction

Conditions considered for planning of tunnels

1. Geometry (Length, Depth, Size)
2. Geological conditions (Soil, Rock, Water)
3. Surface conditions (urban area, mountains)
4. Access to the tunnels (Size of Access Roads)
5. Construction schedule
Introduction

1. Geometry

<table>
<thead>
<tr>
<th>Usage</th>
<th>Typical Area (m²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railroad</td>
<td>20 to 90</td>
<td>20m² for light rail, 90m² for double track bullet train</td>
</tr>
<tr>
<td>Road (Expressway)</td>
<td>70 to 200</td>
<td>Expressway 2 traffic lanes and 1 parking lane</td>
</tr>
<tr>
<td>Road (Highway)</td>
<td>50 to 100</td>
<td>National highways</td>
</tr>
<tr>
<td>Underground River</td>
<td>100 to 300</td>
<td>Used as a reservoir too</td>
</tr>
<tr>
<td>Water</td>
<td>up to 10</td>
<td>Relatively small</td>
</tr>
<tr>
<td>Sewer</td>
<td>up to 30</td>
<td>Main is 6 to 8m in diameter</td>
</tr>
<tr>
<td>Power</td>
<td>up to 10</td>
<td>Relatively small</td>
</tr>
<tr>
<td>Gas</td>
<td>up to 10</td>
<td>Relatively small</td>
</tr>
<tr>
<td>Combined Utility</td>
<td>10 to 25</td>
<td>Size varies</td>
</tr>
<tr>
<td>U/G Railroad Stations</td>
<td>Very large</td>
<td>Constructed by Cut and Cover Methods</td>
</tr>
<tr>
<td>U/G Shopping mall</td>
<td>Very large</td>
<td>Constructed by Cut and Cover Methods</td>
</tr>
<tr>
<td>U/G Parking Garages</td>
<td>Very large</td>
<td>Constructed by Cut and Cover Methods</td>
</tr>
</tbody>
</table>

Conventional Tunneling in Urban Area
Introduction

Cross section of various tunnels

1. Railroad (double track)
2. Railroad (single track)
3. U/G Railroad Stations
4. Expressway
5. Underground river
6. Combined Utility
7. Sewer

Conventional Tunneling in Urban Area
# Introduction

## 2. Geological Conditions

### a. Geology

<table>
<thead>
<tr>
<th>Soil</th>
<th>Sand and Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clay</td>
</tr>
<tr>
<td>Rock</td>
<td>Hard Rock</td>
</tr>
<tr>
<td></td>
<td>Soft Rock</td>
</tr>
<tr>
<td></td>
<td>Fractured</td>
</tr>
<tr>
<td></td>
<td>Swelling</td>
</tr>
</tbody>
</table>

### b. Overburden Depth

<table>
<thead>
<tr>
<th>Shallow</th>
<th>Subsidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep</td>
<td>High Pressure</td>
</tr>
</tbody>
</table>

### c. Ground Water

<table>
<thead>
<tr>
<th>Water Pressure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Amount</td>
<td></td>
</tr>
</tbody>
</table>
Introduction

3. Surface Conditions
   - Mountains
   - Hills and Forest
   - Farmlands
   - Urban Area
   - Heavily Crowded Area
   - Adjacent Important Structures

4. Access to the tunnels
   - Construction Area
   - Access Roads

5. Construction schedule

*Conventional Tunneling in Urban Area*
Introduction

Construction Methods of Tunneling

Conventional
- Drill and Blast
- Mechanical Excavation

Mechanized
- Hard Rock TBM
- Tunnel Bore Expander
- Soft Ground TBM

Conventional Tunneling in Urban Area
Comparison of Construction Methods

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Mechanized</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometry</td>
<td>Large Cross Section</td>
<td>Up to 16m D</td>
</tr>
<tr>
<td></td>
<td>Variable Cross Section</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>Short</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>Long</td>
<td>×</td>
</tr>
<tr>
<td>Geology</td>
<td>Soil</td>
<td>Sand /Grave</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay</td>
</tr>
<tr>
<td></td>
<td>Soft Rock</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>Hard Rock</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>Fractured Rock</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>Swelling Rock</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>High Water Pressure</td>
<td>Up to 1.0Mpa</td>
</tr>
<tr>
<td>Subsurface Settlement</td>
<td></td>
<td>×</td>
</tr>
<tr>
<td>Access</td>
<td>Construction Yard</td>
<td>Large</td>
</tr>
<tr>
<td>Speed</td>
<td></td>
<td>×</td>
</tr>
</tbody>
</table>

Conventional Tunneling in Urban Area
Introduction

Introducing Conventional Tunnelling in urban Area Case Histories in Japan

Case History 1: Onmawashi Park Underground Reservoir Project

- Large cross section, Various size, Low overburden depth

Case History 2: Nagoya Expressway Higashiyama Tunnel

- Sandy soil, Under the residential area, Large Junction

Conventional Tunneling in Urban Area
Case History 1

Onmawashi Park Underground Reservoir Project

The inflow shaft.

Conventional Tunneling in Urban Area
Project Outline

Chapter 1

Conventional Tunneling in Urban Area
## Project Outline

<table>
<thead>
<tr>
<th>Project Name</th>
<th>ONMAWASHI-KOEN Flood Control Tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>KANAGAWA Pref.</td>
</tr>
<tr>
<td>Usage</td>
<td>Flood Control Tunnel</td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Cross Sectional Area</strong></td>
<td></td>
</tr>
<tr>
<td>Section A</td>
<td>430.8m, 254.1m²</td>
</tr>
<tr>
<td>Section B</td>
<td>134.5m, 166.7m²</td>
</tr>
<tr>
<td>Construction Joint spacing</td>
<td>12.0m</td>
</tr>
<tr>
<td>Upper crosscut</td>
<td>12.75m, 58.7m²</td>
</tr>
<tr>
<td>Lower crosscut</td>
<td>430.8m, 18.5m²</td>
</tr>
<tr>
<td><strong>Excavation Method</strong></td>
<td>Top Heading &amp; Multiple Bench NATM with Advancing Center Drift</td>
</tr>
<tr>
<td><strong>Auxiliary Method</strong></td>
<td>Long Fore Piles, Foot Piles, Preload Packs, Face Bolts, etc.</td>
</tr>
</tbody>
</table>
Chapter 1

Project Outline

Conventional Tunneling in Urban Area
Chapter 1

Conventional Tunneling in Urban Area

Project Outline

geological profile

Water bearing sang

Mudstone

Conventional Tunneling in Urban Area
Chapter 1

Features

• Large diameter oblong shaped tunnel for flood control in mudstone. Width: 17.2m, Height: 8.2m, Cross Sectional Area: 254.1m$^2$

• Surface subsidence is critical since there are many houses on the surface with overburden depth of 1.5D.

• Since there are few experiences, it is difficult to predict the influence of large excavation.

Conventional Tunneling in Urban Area
Chapter 1

Evaluation of excavation method

The original design

Excavation method for a standard section

1. Side drift advancing method
2. Top heading advancing method
3. Center diaphragm method

Test excavation was conducted by 2 “Top heading advancing method” because access to the tunnel is restricted. (50m section from starting shaft)

Measurement
- Ground surface settlement
- Convergence
- Ground displacement
- Axial force of support
- Axial force of rock bolt

FEM analysis
- Side drift advancing method

Reevaluation of ground properties
Chapter 1

Evaluation of excavation method

The determination of the excavation method of standard section

Top Heading & Multiple Bench NATM with Advancing Center Drift

Tunnel cross section

Conventional Tunneling in Urban Area
Chapter 1

Conventional Tunneling in Urban Area

1. Enlargement of Top Heading (Test section)

2. Removing steel support

3. Excavation

4. Extending steel support

5. Conventional Tunneling in Urban Area
Chapter 1

Upper section enlargement

Conventional Tunneling in Urban Area
Chapter 1

Conventional Tunneling in Urban Area

Bottom section excavation
Chapter 1

Excavated tunnel

Conventional Tunneling in Urban Area
The secondary lining.

The carriage for placing of reinforcement.

Form for tunnel lining

Conventional Tunneling in Urban Area
Chapter 1

Conventional Tunneling in Urban Area

Tunnel A

Tunnel B

Water shute

Conventional Tunneling in Urban Area
The measuring result

- 10mm
- 20mm
- 30mm

Crown settlement

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Chapter 1

Conventional Tunneling in Urban Area

The measuring result

- The measured value
- The analysis
- The elastic modulus
- The levee crown subsidence
- The inner space displacement

Underground displacement
Chapter 2

Case History 2

Nagoya Expressway Higashiyama Tunnel

Conventional Tunneling in Urban Area
Chapter 2

Conventional Tunneling in Urban Area

Project Outline

Tokyo
Osaka
Nagoya

HIGASHIYAMA Park
No.1 Shaft
Nagoya University
### Project Outline

<table>
<thead>
<tr>
<th></th>
<th>Nagoya City Highway No.1 HIGASHIYAMA Tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Client</strong></td>
<td>Nagoya Expressway Public Corporation</td>
</tr>
<tr>
<td><strong>Usage</strong></td>
<td>Highway (Two-lane)</td>
</tr>
<tr>
<td><strong>Length</strong></td>
<td>2,600m</td>
</tr>
<tr>
<td><strong>Cross Sectional Area</strong></td>
<td>114 ~ 136m²</td>
</tr>
<tr>
<td><strong>Excavation Method</strong></td>
<td>NATM</td>
</tr>
<tr>
<td><strong>Auxiliary Method</strong></td>
<td>Long Forepiles, Foot Piles, Preload Packs, Face Bolts, etc.</td>
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</table>
Project Outline

geological profile

Starting shaft

Arrival shaft

large section junction

Shotcrete Lining Concrete

Conventional Tunneling in Urban Area
Chapter 2

Conventional Tunneling in Urban Area

Features

1. Two-lane expressway tunnel in sandy and clayey ground with overburden depth of 20 to 40m.

2. The underground water level is 5m above the crown, horizontal boring from the heading is conducted to lower the water table.

3. Low-rise residential buildings and major trunk roads are on the surface and also the tunnels cross many utility lines.

4. One tunnel starts from No.1 shaft, the other starts from the large section junction.
Chapter 2

Conventional Tunneling in Urban Area

Large junction structure

Starting shaft

No.1 shaft

Cross cut

30.0m
The three-dimensional FEM analysis.

- The model figure.
- The analytical result

**Chapter 2**

Conventional Tunneling in Urban Area

- The three-dimensional FEM analysis
  - The node number: 19,740
  - Number of element: 24,297
  - The ground is modeled in linear elastic solid.
  - Number of analysis step: 26 steps

- The original design of the auxiliary method and supports are insufficient.

- The additional auxiliary method is applied.
  - The tie-rod method
The tie-rod method

The crown is suspended by the anchors from the surface.

Conventional Tunneling in Urban Area
Chapter 2

Conventional Tunneling in Urban Area

The tie-rod method

Bearing plates and anchors on the surface

Connection of the anchors in the tunnel
Conventional Tunneling in Urban Area

The measuring result

The tie-rod anchor

Bearing plate

The settlement of 40mm

The settlement of 100mm

Tunnel

27m

WEST

EAST
The secondary lining completed

Conventional Tunneling in Urban Area
Chapter 3

Twin Arch Junction Beams
Combination of mechanized tunnelling and conventional tunnelling

Even if technologies of mechanized tunnelling methods are well developed, still conventional tunnelling methods need to be utilized in some areas.
The junction structure of two traffic tunnel need to be constructed underground.

Twin Arch Junction method is proposed to built underground intersection of expressways.
Chapter 3

Construction method

Conventional method
(Open cut method)

Long construction period
Ill-Effects on the surface environment

Restoration

Conventional Tunneling in Urban Area

Twin Arch Junction Beams

No ill-effects on the surface environment

Tunnel boring machine

Before construction

Earth-retaining structure

Road surface lining.

Excavation

Structure construction

Back filling

Restoration

Conventional method
(Open cut method)

Working zone installation

Long construction period
Ill-Effects on the surface environment

Working zone

Conventional Tunneling in Urban Area

Pipe roof

Ramp shield

Main shield

Excavation

Reinforcement
Conclusions and references

Tunnelling in urban area

1. Mechanized tunnelling
   Machine cost is high
   Hard to adapt if the cross section is changed

2. Conventional Tunnelling
   Will be used under more difficult conditions

Technologies to be developed

1. Numerical analysis to evaluate ground behavior
2. Developing auxiliary methods, such as ground stabilization, ground freezing, underground water control